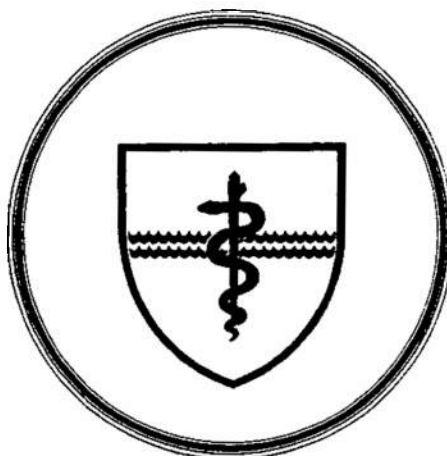


NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

SUBMARINE BASE, GROTON, CONN.



REPORT NUMBER 1050

ACCEPTABILITY OF LOW LEVEL WHITE LIGHTING
IN THE CONTROL ROOM AT SEA

by

S. M. Luria and D. A. Kobus

Naval Medical Research and Development Command
Research Work Unit M0100.001-1023

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23 May 1985

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SUMMARY PAGE

PROBLEM

To evaluate the acceptability of low level white lighting in the control room of a submarine at sea.

FINDINGS

The low level white lighting was judged to be acceptable and generally superior to red lighting when the entire control room was illuminated. However, when the control room was rigged for black and only the lights over the plotting tables were on (in addition to the light in the passageway leading to the control room and the adjoining navigation room), the white light appeared to be much brighter and more distracting than the red light.

APPLICATION

These results are pertinent to any decision to substitute low level white lighting for red in the control room. They suggest that low level white lighting would be completely acceptable if the lights that remain on when the room is rigged for black are dimmer than when the entire control room is illuminated.

ADMINISTRATIVE INFORMATION

This investigation was undertaken for the Naval Underwater Systems Center, New London, Work Order Ref. No. N0002485WR10264 under Program Element 64520, Job No. A47232, Principal Investigator, Frank Molino, Code 3251. The research was conducted under Naval Medical Research and Development Command Research Work Unit M0100.001-1023 - "Enhanced visual performance on submarines". It was submitted for review on 2 Apr 1985, approved for publication on 23 May 1985, and designated as NSMRL Report No. 1050.

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ABSTRACT

Low level white (LLW) lighting was evaluated as a substitute for red lighting by the watchstanders in the control room of the USS BOSTON (SSN703). A questionnaire was completed by each man at the end of a watch period under each lighting condition. The men almost unanimously preferred LLW to red. However, when the control room was rigged for black the LLW lighting used over the plotting tables and in the adjoining spaces, when seen peripherally, appeared much brighter and more distracting than when the red lighting was used. This problem can be solved by using dimmer LLW for the lights that will be left on when the control room is rigged for black.

INTRODUCTION

Several lighting conditions are used on submarines. During the day the working compartments are illuminated by white light to intensities of at least 25 foot-Lamberts (fL). At night, selected compartments such as the control room and the adjoining compartments are put under reduced illumination. Until now, red light has been used, although in recent years sonar rooms have been converted to blue light.^{1,2} Red light has been used since World War II, because complete dark adaptation, as measured by the ability to detect small spots of light, is achieved more quickly after exposure to red than to any other color.³

The procedure is to turn the red lights on half an hour before coming to periscope depth. The crews consider that this produces a considerable degree of dark adaptation. When the submarine comes to periscope depth, most of the lights are turned out in the control room ("rig for black"), leaving at most only dim red lights over the plotting tables. The overhead lights remain off until periscope operations are completed. If the submarine is expected to come to periscope depth several times during the night, the red overhead lights in the control room are not turned on at all; they remain off throughout the night.

Consideration is now being given to substituting white light for the red light for several reasons. First, red light has always been unpopular; it is impossible to read color coded charts or other printed matter in red light, and the crewmen complain that it is fatiguing to work under red light for extended periods of time. Second, many studies have shown that the relative advantage of red light is strongly dependent on the intensity of the adapting light: as the intensity decreases, the relative advantage of the red⁴ light also decreases.³ At the intensity used on submarines, the advantage of the red is small and probably not of operational significance.³ Third, the requirement for a large number of men to be dark adapted no longer exists as it did during the days of the diesel submarines. Only the periscope operator needs to be dark adapted on a nuclear submarine. Fourth, it is quite probable that the man trying to see at night often does not require complete dark adaptation.³ This is the case even on those nights when there is only starlight.³ Moreover, the periscope operators are often trying to detect shapes and shadows rather than small spots of light, and they are more concerned about their ability to see during the first few seconds of periscope viewing than after the more extended period of time required for maximum sensitivity. Recent work has shown that the ability to detect shapes and shadows within 10 seconds against a background intensity equal to the brightness of the starlit sky is not significantly different after adaptation to red or white light in the range of intensities typically found in submarine compartments under red illumination.⁵ For all these reasons, it has been proposed to substitute red lighting with white lighting matched in brightness and

thus to avoid the drawbacks of red lighting.

Before a final decision to substitute white light for red can be made, however, its acceptability to the men who stand watch under this light must be ascertained. Similar evaluations of white light have been conducted in the sonar rooms of eight submarines, and it has been received favorably.⁶⁻⁸ As a result, Squadron 12 has recommended the installation of low level white,⁹ (LLW) light in sonar compartments throughout the submarine force.

The control room, however, presents a different set of problems. The displays are different, and the question of periscope operations must be considered. This report gives the results of a comparative evaluation of the red and white lighting in a control room at sea.

METHOD

Lighting conditions- Evaluations were made after using red and LLW lighting for a 30 min pre-adaptation period prior to coming to periscope depth. In addition, two sets of evaluations were made after working under the LLW for a six hour period.

Light levels- The intensity of the red light at various locations in the control room was measured to determine the density necessary for the matched LLW filter. Photometer readings taken under low levels of chromatic illumination are inaccurate;¹⁰ they may err by as much as 0.2 log unit. Nevertheless, photometer readings are the only way to obtain such measures, and, in any event, corrections can be made using the nomograms reported by Kinney.¹¹ This procedure allowed us to manufacture lighting conditions that were matched for intensity.

The values varied from one station to another (Table I). The light level on the plotting table was much higher than at the other stations, because the desk lamps are much closer to the work surface than are the lamps which illuminate the other stations.

Procedure- The watchstanders were grouped into three sections; each was on duty for six hours. Each section evaluated each illuminant at a different time. Two sections gave their evaluation of the LLW first, and the third section evaluated the red light first. The number of men in each watch varied, however, depending on the operations which were being carried out. A total of 69 evaluations were obtained.

Questionnaires were tailored to each watch station. Particular attention was given to those tasks which the watchstanders themselves, when interviewed before the study began, considered most difficult. All were designed to evaluate how well the duties could be performed under each illumination. A sample questionnaire, designed for the fire control station, is shown in Appendix A. The watchstanders were asked to rate

the illumination on a scale of 1 to 10 for the ease with which it permitted such tasks as reading colored plots, reading publications, troubleshooting the equipment. The final question, rating the overall desirability of the light, appeared on all questionnaires. The evaluations made after an entire watch under the LLW were analyzed separately.

RESULTS

Acceptability

The mean acceptability rating, averaged for all questions for all watchstanders, was 3.4 ± 2.7 for the red light and 7.6 ± 2.4 for the LLW, with a rating of 1 being the lowest and 10 the highest. The mean rating for the LLW was very significantly greater ($p < .001$) than that for the red.

Some questions were asked of all watchstanders. The mean ratings for the final question, the desirability and effectiveness of the light, were 3.5 ± 3.0 for the red and 8.1 ± 2.5 for the LLW ($p < .001$). The men were also asked to rate how tired their eyes became during the watch. The mean rating under red was 3.8 ± 2.8 ; under white it was 8.0 ± 2.5 ($p < .001$).

Many of the watchstanders read charts, publications, and other printed matter during the watch. They rated the difficulty of doing so under the two lights. The mean rating under red was 2.8 ± 2.5 ; under LLW it was 8.5 ± 1.9 ($p < .001$). In addition, they were asked whether or not they had a headache at the end of their watch. Only a total of 4 men reported headaches, too few for a statistical test.

They were also asked whether they felt too tired to stay up and carry out any other assignments they might have, or whether they felt they had to go to sleep immediately after the watch. Fourteen percent of the men under LLW and 40% of those under red light said they were too tired to do anything more. However, this difference was not statistically significant ($p < .10$).

Evaluations after 6-hour watch under low level white

The questionnaire administered after the six-hour exposure to LLW asked for only for opinions about the white light and comparisons with red, rather than for numerical ratings. Only one of the 20 men making these evaluations had a negative opinion of the LLW light; he did not identify his watch station. All the other evaluations were positive, with the most enthusiastic ones coming from the plotters. Even the man who wrote the sole derogatory comment wrote that it was "better than rig for red." His complaint (see below) was that the white light was unsatisfactory under rig-for-black, a comment echoed (with less emphasis) by the Quartermaster, the Officer of the Deck, and the Time Frequency

Plot watchstander. No one, however, concluded that the white light should not be adopted. Appendix B contains some selected comments from the watcherstanders.

Problems

Although the dim white light was strongly preferred by nearly everyone over the red light, one notable problem emerged during the trials. The LLW light, although matched in brightness to the red for direct viewing, was much brighter than the red with peripheral viewing. The reason is that the periphery of the retina has few cones (daytime receptors), whereas the center of the retina has few rods (nighttime receptors). In equating the brightness of the white and red for direct viewing, the match was made for the cones which are more sensitive to red light than the rods. Thus, when the colors are seen out of the corner of the eye--that is, when the light is stimulating the rods--the white light appears to be much brighter than the red, to which the rods are less sensitive.

This is not annoying when the entire compartment is illuminated by LLW, but it proved to be unacceptable when the control room was rigged for black while the plotting tables adjoining the passageway and navigation room remained in LLW light. The white light in these spaces appeared to be much brighter and much more distracting than red light.

At the plotting tables, the men complained that the LLW light appeared to cast more shadows than the red. This may result from a higher level of adaptation in the periphery of the eye, making shadows seen by the fovea seem darker. All the plotters rated the white light more highly acceptable than the red, but they appeared to agree that it must be reduced in brightness when the control room is rigged for black.

CONCLUSIONS

The LLW light was almost unanimously preferred to the red light. It makes it easier to carry out most of the duties in the control room while resulting in fewer complaints about eye-strain and fatigue. However, white light which has been matched in brightness to red light for direct viewing (that is, for tasks such as reading and looking at indicators) appears to be much brighter than red light when seen out of the corner of the eye. Thus, when the control room was rigged for black, the dim white lights over the plotting tables and in the adjoining compartments and passageways were unacceptably bright and distracting. The problem was solved by hanging black curtains to screen the light from the forward part of the control room, while the plotters found a way to reduce the intensity of the white light in the table lamps. This did not lead the crew to reject the white light. Indeed, the black curtains appear to be rigged routinely to shroud the forward part of the control room.

Another solution is simply to install filters of greater density in the areas adjacent to control. A preliminary experiment indicated that an additional density of 0.8 (that is, filtering out an additional 85% of the light) would equate the brightness of the white light, as seen peripherially, with the red. The men at the plotting tables are always able to dim the intensity of their light by adjusting the opening in their desk lamps.

Although this solution is quite simple in principle, it makes it necessary to manufacture filter sleeves of two densities and to ensure that the correct sleeves are installed in the various locations. Additional evaluations at sea should be performed with these modifications.

ACKNOWLEDGMENT

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Table I. Intensity levels (foot-Lamberts) at various control room stations

Station	Red	White
Helmsman/Planesman	.020	.023
Diving Panel	.023	-
Fire Control	.027	.033
Plotting Table	.80	.15

APPENDIX A

SAMPLE QUESTIONNAIRE

Watch Station: Fire Control

Color of Light : _____ Time of Watch _____

Rate the difficulty of reading colored plots (1=difficult; 10=easy)

Comments?

Rate the difficulty of reading pubs (1=hard; 10=easy)

Comments?

If you had to troubleshoot equipment, rate the difficulty (1=hard; 10=easy) under this light.

Comments?

If you had to go through other compartments (sonar, CCC, passageways), rate the difficulty or discomfort of the changes in brightness and the time to readapt (1=hard; 10=easy and quick).

Comments:

Rate how tired your eyes got during the watch (1=tired; 10=not tired at all).

Comments?

Did you get a headache?

Do you feel like staying up and doing other things after this watch or do you feel you must go to sleep right away?

Rate the quality, desirability, effectiveness, etc., of this light (1=bad; 10=good).

APPENDIX B

SELECTED COMMENTS FROM WATCHSTANDERS

XO

The XO pointed out that it is particularly hard on the OOD to have to wear red goggles all night when the control room is not rigged-for-red. It is much less tiring if the control room can be illuminated with low level white light and OOD need not wear goggles.

Navigator

The navigator noted that his eye adapted about as quickly under low level white as with red light, when looking out the periscope. He found it much easier to pilot the ship and work with the charts using the white.

OOD

An OOD commented that he could not keep logs or see displays with red light, "even putting nose to the panel."

Chief of the Watch

Two COWs commented that although white is more desirable than red, the BCP was somewhat dark. One COW commented that going from low level white to bright white was easier on the eyes than going from red to bright white. Another comment was that under red light it was not possible to do a lot of normal evolutions without a flashlight.

Quartermaster

The QMs commented that the low level white light was too bright at periscope depth and at battlestations.

Diving Officer

One commented that it is much easier to adjust when walking from a lighted space into the dim white light, or vice versa. Another comment was that most indicators on the Ship Control Panel are red; when using low level white, there are shadows on the gauges; he was of the opinion that the red lamps on the SCP should be replaced with dim white lamps.

Helmsman/Planesman

One helmsman wrote that it is always difficult to read the indicators under red light because the indicators themselves are red. The white light, on the other hand, is excellent, because it is possible to read name tags on key valves without a flashlight. One helmsman strongly preferred the red light; he complained that the white lights cause shadows.

Plotters

The plotters, predictably, liked the low level white. One commented that it would be very desirable "for section tracking, especially if the majority of the watch was spent at PD."

Fire Control

One fire control watch-stander commented that with the dim white light it was much easier to adapt going from one space to another.

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